Tijdschrift voor Economie en Management
Vol. LII, 3, 2007

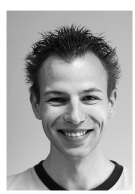
Clinical pathways and operations management: it takes two to tango

By E. Demeulemeester, W. Sermeus, J. Beliën and B. Cardoen

Erik Demeulemeester
Research Center for Operations Management
Department of Decision Sciences and Information Management
Faculty of Economics and Applied Economics
(K.U.Leuven)

Jeroen Beliën
Research Center for Operations Management
Department of Decision Sciences and Information Management
Faculty of Economics and Applied Economics
(K.U.Leuven)
Postdoctoraal onderzoeker Fonds Wetenschappelijk Onderzoek – Vlaanderen

Walter Sermeus
Center for Health Services and Nursing Research
Faculty of Medicine
(K.U.Leuven)



Brecht Cardoen
Research Center for Operations Management
Department of Decision Sciences and Information Management
Faculty of Economics and Applied Economics
(K.U.Leuven)

ABSTRACT

In this paper it is shown that quality of care in a hospital setting is not solely determined by the medical treatment of patients. Organizational structure clearly contributes to the qualitative performance measures too. In particular, clinical pathways could be specified in which both components are integrated. Moreover, the operating theater is identified to be an instrument in those clinical pathways that enables the health manager to exploit the relations and dependencies between facilities. This results in an improved patient flow and an adequate use of scarce resources. It will be shown that algorithms and software tools can assist in increasing the performance of the hospital as a whole. These improvements could be gained both through visualization and optimization. Some Belgian case studies will be referred to in order to show the practical value of the academic approaches.

I. INTRODUCTION

The health care sector goes through a major reform. This has many reasons. First, the costs of health care are rising up to 15% in the United States (US) and more than 10% in Europe. This is due to the increasing needs of a greying population, but also due to technological and pharmacological innovations that are really widening the possibilities for diagnosis and treatment. Second, there is a shift in the role of patients, going from a more passive role into a role of active consumers of care. Patients want to be informed and involved. Third, there is growing attention to quality and safety. The main drive comes from the *to err is human* report from the Institute of Medicine (www.iom.edu) in 1999 (Kohn et al. (1999)). This report indicated that as many as 44.000 to 98.000 US citizens die in hospitals each year as the result of medical errors. Even using the lower estimate, this would make medical errors the eighth leading cause of death in this country – higher than motor vehicle accidents (43.458), breast cancer (42.297) or AIDS (16.516). The report was publicly discussed in the Senate and was the start of an overall hospital reform across the US. Most important in this discussion is that people are not blamed – to err is human indeed – but that the focus should be on improving the system. The Institute of Healthcare Improvement (IHI) is the force behind this tremendous reform. Through projects and campaigns, continuous attention is asked for quality and safety. The actual *5 Million Lives Campaign* is an initiative to protect patients from five million incidents of medical harm from December 2006 until December 2008 (www.ihi.org). The attention to safety and quality given in the US, is followed by many other countries. In Belgium, Van den Heede et al. (2006) conclude that about 6% to 7% of all admissions in Belgian hospitals have unwanted adverse events. In 2007, a study in the Netherlands (www.nivel.nl) revealed that adverse events were seen in 5.7% of all admissions in Dutch hospitals. 40% of them seems to be preventable (de Bruijne et al. (2007)).

Not only the figures, but also the explanations are in line with the findings in the US. Most of them are supported by publicly available case reports. The United Kingdom (UK) has built its agenda on quality and patient safety on reports of high mortality in children's heart surgery at the Bristol Royal Infirmary. An official inquiry was started, mainly as a learning case about the quality of the health care system rather than on specifically focusing on the local problems in Bristol.

In their final report, the commission stated that although it started as a "Whodunnit?" question, the answer seems to be that "the system has done it". In the executive summary of the inquiry it was concluded that "It is a tragedy that many well-intentioned people worked hard to do well but did in fact dreadful harm. Health care has a long tradition of "muddling through" with an inadequate use of resources. Further reasons were poor teamwork and management, inadequate leadership, a closed "club" culture and the absence of systems to monitor performance. Safety has been forgotten and evidence has been ignored. They were interested in as many people passing through the system as possible for a cost that is as low as possible." (Bristol Royal Infirmary Inquiry (2003)). The Netherlands is recently confronted with a similar report in the UMC St. Radboud hospital in Nijmegen, in which the cardiosurgical department was closed by the health inspection (IGZ (2006)). An external medical audit revealed a higher average mortality in cardiac surgery. The main explanation was focused on weak leadership, not following protocols, fragmentation, low communication, etc.

It becomes more and more obvious that it is not sufficient that health providers acknowledge the need to improve their quality of care, we should question how to structure the health delivery process and how to improve the major pitfalls such as the inefficient use of resources and the lack of communication and protocols. In order to do so, we will introduce in Section II the concept of clinical pathways or care pathways. Since these pathways can link both the medical part and the organizational part of health care, they clearly contribute to the overall quality of care. In Section III, we will focus on the organizational issues and show how one component of these clinical pathways, namely the operating theater, can influence processes and resources dispersed throughout the entire hospital. This high level of interaction and interdependency obviously implies that the operating theater is crucial for improvement identification and that an adequate use could lead to a significant decrease in inefficiencies, both for the patient and the hospital or personnel. In Section IV, we will look at the implications of the surgery schedule on the flow of patients through the clinical pathways, whereas in Section V, some applications and algorithms for increasing the stakeholder satisfaction through surgery scheduling will be provided. Finally, in Section VI, we will summarize important findings and point at interesting issues for future research.

II. CLINICAL PATHWAYS

Clinical pathways are often seen as a methodology to deal with the quality issues mentioned in the previous section. The methodology was originally grown from PERT (Project Evaluation and Review Technique) and CPM (Critical Path Method) techniques, but transformed into «clinical» instead of «critical» pathways because of the very specific nature of health care. When clinical pathways were developed in the mid eighties, their major focus was on reducing the length of stay (LOS) of patients. The first systematic use was found in the New England Medical Center in Boston (USA) in 1985 as a response to the introduction of Diagnosis Related Groups (DRGs) in 1983. The actual focus is mainly on improving the quality of care.

Clinical pathways are defined as "Schedules of medical and nursing procedures, including diagnostic tests, medications and consultations, designed to effect an efficient, coordinated program of treatment", which is a very narrow definition. The European Pathway Association broadened this definition to "A methodology for the mutual decision making and organization of care for a well-defined group of patients during a well-defined period. Defining characteristics of care pathways include:

- an explicit statement of the goals and key elements of care, based on evidence, best practice and patient expectations;
- the facilitation of the communication, coordination of roles and sequencing of the activities of the multidisciplinary care team, patients and their relatives;
- the documentation, monitoring and evaluation of variances and outcomes;
- the identification of the appropriate resources.

The aim of a care pathway is to enhance the quality of care by improving patient outcomes, promoting patient safety, increasing patient satisfaction and optimizing the use of resources (www.e-p-a.org)".

In a Belgian project on clinical pathways, funded by the Federal Minister of Health, almost 800 health professionals were surveyed on their knowledge and attitude towards clinical pathways (Sermeus et al. (2005)). About 50% was familiar with the concept of clinical pathways, varying from 20% for physiotherapists up to 70% and 80% for medical doctors and nurses. The main benefits they see in clinical pathways are the improvement of the multidisciplinary communication and collaboration and the increased overview in what every health professional is contributing to the care of the patient.

Clinical pathways have two related components: content and organization. A clinical pathway is not only "treating the right patient right", what is the main focus in diagnoses and treatments. Clinical pathways are "treating the right patient right at the right time and at the right way, by the right person" (Bandolier (2003)). Clinical pathways always deal directly with implementation. Who will do what when is probably the most asked clinical pathway question. In actual clinical pathways we see that experience-based clinical pathways are more and more replaced by evidence-based pathways based on widely accepted clinical guidelines. The organizational component, however, has not the same quality as the clinical component. In the UK, clinical pathways are highly clinical, with minor impact on changing the organization. In the US, clinical pathways and organizational change strategies, such as business process reengineering, are separated and not linked. In the Netherlands, there is a long tradition in patient logistics or organizational management in health care. The link with clinical pathways is very recent. In Belgium, operational management in health care was always focusing on secondary processes, but rather seldom on primary processes. Building clinical pathways and linking them with the optimization of organizational processes is rather new. Yet it is obvious that not only the content component, but also the organizational component should be research based and optimized. The system approach to which so many quality reports refer, implies that content and organization are studied together and not as two separate entities. The link of clinical pathways and operational management now becomes obvious.

Operations management is concerned with the ways of achieving the most effective and efficient use of an organization's resources, such as its financial and human resources, its infrastructure and equipment. In order to successfully apply operations management techniques in hospital settings, one first needs to have a profound insight into the dynamics of the system. Clinical pathways are the perfect instrument to get this insight. Consider, for instance, the decision to increase the capacity preserved for knee surgery consultation. Such a decision has a direct impact on the use of other resources, for instance, the operating room time, radiology equipment and nursing services needed for knee patients. The clinical pathway that describes the path of these patients provides detailed information on the amount and the type of resources that would be affected.

The allocation of capacity and resources is hence not an isolated question and is related to the patients and the patient flow. The operating theater is generally considered as the most critical resource inside hospitals since it is one of the main cost drivers and almost all patients have to pass through it. Therefore, the operating room schedule is an appropriate instrument to manage patient flow and, consequently, the timing and occupancy of other important resources like nursing staff, beds, anaesthetists, specialized equipment, radiology and so on. This implies that the operating room can be seen as the engine that drives the hospital (Litvak and Long (2000)). Indeed, what happens inside the operating room dramatically influences the demand for resources throughout the rest of the hospital. For instance, after surgery, a patient often occupies a bed and requires nursing services for recovery. Certain types of surgery entail preceding tests (e.g. blood analysis) or post-surgery treatments that have to be carried out by correctly skilled staff. In the remainder of this paper, we will hence limit the focus to the contributions that can be obtained through the organization of the operating theater. Some case studies will be introduced to highlight the practical value of this research.

III. HOW SURGERY SCHEDULING DETERMINES RESOURCE UTILIZATION

In general, we can distinguish between three levels of surgery scheduling. First, there is the strategic level in which one has to determine how much operating room time will be assigned to the different surgeons or surgical groups. This level is often referred to as case mix planning (Blake and Carter (2002)). Second, there is a tactical level in which the master surgery schedule is developed. This schedule can be seen as a cyclic timetable that defines the number and type of operating rooms available, the hours that rooms will be open, and the surgeon or surgical groups to whom the operating room time is assigned (Blake et al. (2002)). On the third and final level, individual patients or cases can be scheduled on a daily base. In this paper, we will focus on the tactical and operational level.

A. *Tactical level*

Beliën et al. (2006) developed a model that, after implementation in a software system, visualizes the impact of the operating room schedule on the demand for various resources throughout the entire hospital. It has been widely accepted that visualization is a simple yet powerful tool for managing complex systems like health care service units. The paper presents an example of a scheduling tool that visualizes the consumption of various resources as a function of the master surgery schedule. The system does not provide an online visualization of available and occupied resources during the daily working of a surgery hospital. It is neither a simulation package for analyzing the existing system and a limited number of alternative scenarios. The extremely intuitive graphical user interface (GUI) visualizes the impact on resource occupancy of modifications in the master surgery schedule. To this aim, schedulers can easily switch surgeon blocks and immediately see the consequences with respect to the expected use of various resources on a cyclic time axis.

The visualization tool serves two purposes. First, it eases the development of workable surgery schedules by visualizing possible resource conflicts. Second, it might be useful to convince surgeons during the master surgery schedule bargaining process to accept a surgeon block switch. Visualizing a resource conflict is often far more persuasive than hours of discussion with surgeons that are dissatisfied for not being scheduled by their preferences.

Beliën et al. (2006) describe a case study in a large Belgian surgery unit, hereby illustrating how the software can be used to assist in building better master surgery schedules. This case study concerns the surgical day-care center of the university hospital Gasthuisberg, situated in Leuven, Belgium. As the name suggests, this ambulatory center processes only outpatient admissions. To give an idea of the size of this surgical unit, in 2004 12,778 surgical interventions have been performed, making up for more than 15,000 hours of total net operating time. The operating theater consists of 8 rooms in which, in total, 27 different surgical groups, divided over 13 surgical and medical disciplines, have been assigned operating room time. Each operating room is open from Monday to Friday from 07.45 am till 4.00 pm. No elective surgery takes place during the weekends. Each operating room is allocated for at least half a day to the same surgeon. The current master surgery schedule can be called cyclic since it basically repeats each week with the exception of three block allocations that alter each week between two surgeons.

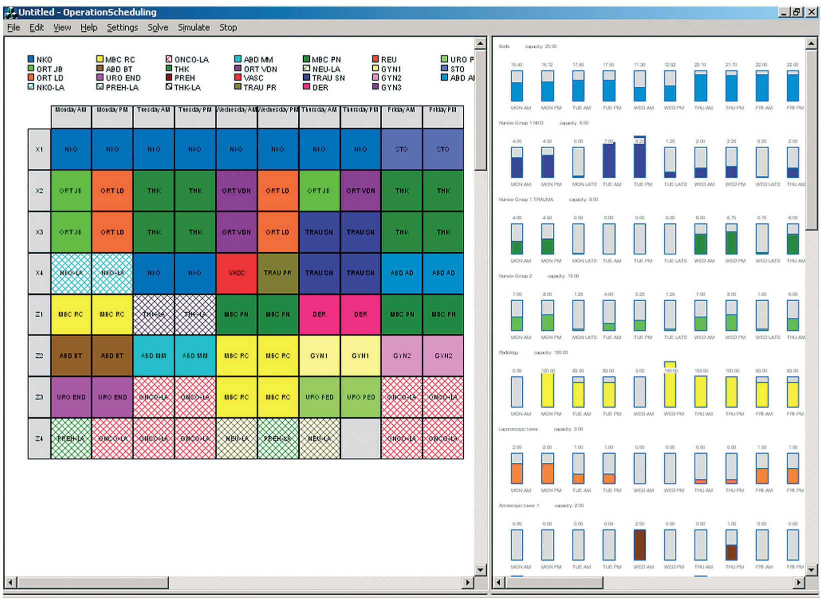
In this case study, twelve critical resources have been identified that all share the following three properties: (1) expensive, (2) limited in capacity and (3) the consumption pattern is directly linked to the operating room schedule. These twelve resources can be distinguished into five groups. First of all, certain types of surgery require the patient to be lying and transported in a bed (1). Second, there are the human resources that consist of: three skill-specific groups of nurses (2, 3 and 4), anaesthetists (5) and anaesthetist-supervisors (6). Third, some surgical interventions involve expensive material resources: laporoscopic towers (7), artroscopic towers type 1 (8) and type 2 (9) and lasers type 1 (10) and type 2 (11). Finally, there is the radiology department (12).

Figure 1 shows a print screen of the GUI with the current surgery schedule for the odd weeks. The GUI visualizes the surgery schedule and the resulting resource use for a given master surgery schedule. Moreover, it allows the user to easily modify an existing schedule and view the impact of a change in the schedule on the use of the various resources. The main window is divided into two panes. In the left pane, the master surgery schedule is shown. The columns in the grid represent the time periods from Monday am to Friday pm. The eight rows represent the eight operating rooms X1-X4 and Z1-Z4. Above the grid, a legend with the surgical groups is shown. Each surgical group has its own color and style. In this case, the style refers to the type of anaesthetic. If the patients are completely anaesthetized during surgery, the surgeon block is colored solidly. Otherwise, when the patients are not fully anaesthetized, the block is arced. The schedule can easily be changed or built from scratch by dragging and dropping the surgeons to the timetable cells.

Each assignment introduces a demand for resources in the system. The expected occupancies of these resources over time are represented in the right pane. A resource is visualized by a row that exists of different bars each representing the resource consumption during a particular time instance (in Figure 1, seven resources are visible). To accomplish this visualization, the system needs as input the resource usages over time corresponding to each surgeon block. Each resource has its own time horizon. The granularity does not necessarily coincide with that from the surgery cycle time horizon. As an illustration, consider the nursing resources for which on each day an extra time unit

FIGURE 1

Print screen of the GUI showing the operating room schedule (left pane) and the impact on the usage of different resources (right pane)



is added after the afternoon block. This extra resource unit represents the late shift. Furthermore, for each resource a capacity can be specified that is not necessarily fixed over the total time horizon.

B. *Operational level*

The utilization of the diverse resources determined on the tactical level depends on an average or expected population of patients. The specific or actual patient population of a surgery day, however, may vary from the expected population. This reinforces the need to have an adequate planning on the level of individual patients too. Many detailed conditions can be incorporated on this operational level. When there is, for instance, only one specific instrument set available, we cannot simultaneously schedule two surgeries for which the instrument set is needed since this would result in a demand for two sets. It is hence a necessity to check the surgery schedule for resource conflicts. When such conflicts occur, one should try to change the sequence in which surgeries will be performed and as such try to influence the resource utilization in the conflicting periods of the surgery day. In Section V.B, a model will be briefly introduced that manages to avoid resource conflicts on the one hand and optimizes quality of care on the other hand.

IV. HOW SURGERY SCHEDULING DETERMINES PATIENT FLOW

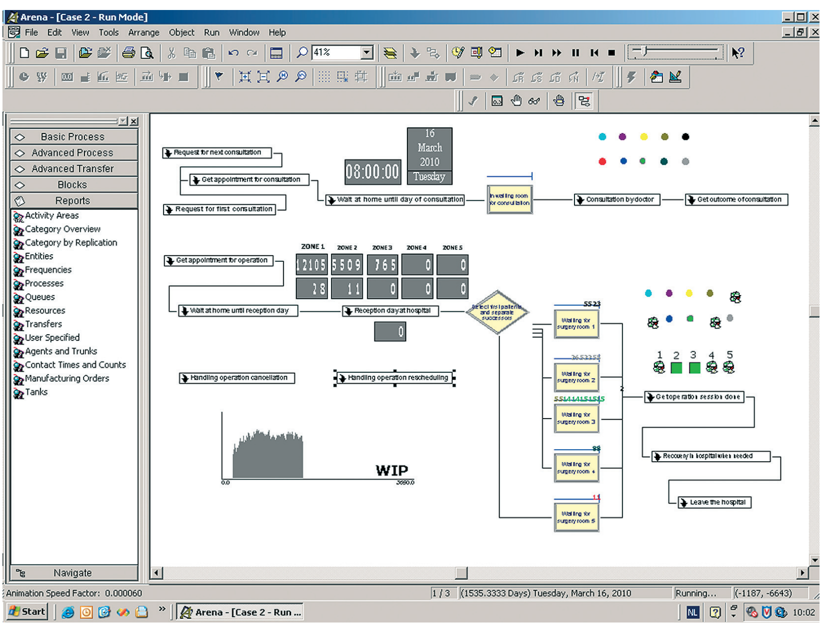
In the previous section, we indicated that the surgery schedule significantly influences the use of resources over time. However, when there is a change in the resources of a hospital, there will probably be an impact on the patient flow too. We will illustrate this proposition on different levels of the surgery scheduling process by means of three small examples. First, suppose that patients have to wait on average one month for their orthopaedic surgery to be performed. Decreasing the total surgery time assigned to the orthopaedic department would then lead to an increase in waiting time since surgeries will now be performed at a slower pace. Note that a huge increase in waiting time would probably cause patients to have their surgery in a competitive hospital. Searching alternative care in other hospitals is often referred to as doctor shopping and becomes increasingly important (Yeung et al. (2004)). Second, a utilization of the operating room that is near to 100% could also, for instance in combination with emergencies, lead to a lengthened stay of patients in the hospital. Since emergency surgeries are prioritized, the program of the elective surgeries could accumulate significant delays. This implies that time is lacking at the end of the day to perform some of the elective surgeries. Postponing the surgeries of hospitalized patients is expensive and should consequently be avoided. As a final example, we could think of the interaction between the surgical capacity of a doctor and his or her consultation capacity. Depending on the type of surgery, a patient has to be consulted several times by the surgeon. These consultations may be performed before and/or after the surgery and can be characterized by a large spread in time. It should be clear that multiple consultations coincide with the performance of one single surgery. Therefore, it is not unrealistic that an increase in surgical capacity for a specific surgery type could lead to problems when the consultation capacity is not adjusted accordingly. Patients will face longer waiting times, which eventually deteriorate the patient flow. Note that this example strongly represents the integration of multiple care steps described by the clinical pathways.

In order to detect anomalies as represented in the previous examples, we developed a decision model in which clinical pathways are simulated. A print screen of this simulation tool, which is implemented using the Arena software, is depicted in Figure 2. The goal of this model is to simultaneously analyze the utilization of multiple resources (operating rooms, hospital wards, surgeons, etc.) and the patient flow through the healthcare system (time in waiting room for consultation, time between request for surgery and day of surgery, etc.).

The model applies to a generic hospital setting and allows for the simultaneous integration of 15 clinical pathways. The generic nature stems from the common structure of the different clinical pathways: whether we are looking to orthopaedics or cardiology, each pathway can be represented as a sequence of consultations and/or surgeries and could hence be evaluated using the discrete-event simulation model.

FIGURE 2

Print screen of the clinical pathway simulation tool



This evaluation can be executed on a strategic, tactical and even operational level. We have to add that the model does not include automatic optimization algorithms. This means that it is suited to represent the current clinical system and to conduct a detailed sensitivity analysis: “What would happen to the performance of the system if we would introduce measure X?”. Note that the information that originates from the sensitivity analysis enables the user of the model to enhance the performance by trial and error. We refer to Cardoen and Demeulemeester (2007) for detailed information on the simulation model. In this research paper, the applicability of the model is illustrated by means of two case studies. The first case study deals with the simulation of both the consultation and the surgery suite of multiple clinical pathways for a single orthopaedic surgeon (Ziekenhuis Netwerk Antwerpen), whereas the second case study focuses on the surgery suite of an entire cardiac catheterization facility (Universitaire Ziekenhuizen Leuven).

V. HOW TO DETERMINE A QUALITATIVE SURGERY SCHEDULE

Now that we are aware that the surgery schedule determines the resource utilization and the corresponding patient flow, we could determine how a qualitative surgery schedule should look like. In this section, some algorithmic procedures will be presented for constructing adequate surgery schedules, both on the tactical and the operational level. These algorithms should assist the health manager in the scheduling process and contribute with respect to the scheduling speed and the scheduling quality since complex interactions (see Section III and IV) can be incorporated.

A. *Tactical level*

1. Leveled resulting bed occupancy

The visualization system described in Section III could be complemented with an optimization component. An optimization component consists of one or more intelligent search procedures that can be applied to automatically generate a qualitative surgery schedule with certain favorable properties. Hence, the tool does not only visualize possible resource conflicts, but also actively searches for schedules that try to avoid these resource conflicts as much as possible. To this aim, the software searches a schedule in which the resulting resource occupancy is leveled as much as possible. In this way, the system is maximally protected against unexpected peaks in these occupancies. The optimization component can also prove to be useful for persuading hospital managers to invest in extra resource capacity. Insufficient resource capacities may not always be visible at first sight. It may, for instance, be the case that, although enough resource capacity is available for the individually summed needs for all resources over all surgeons, still no schedule can be found that provides enough capacity of each resource for each surgeon at each time instance.

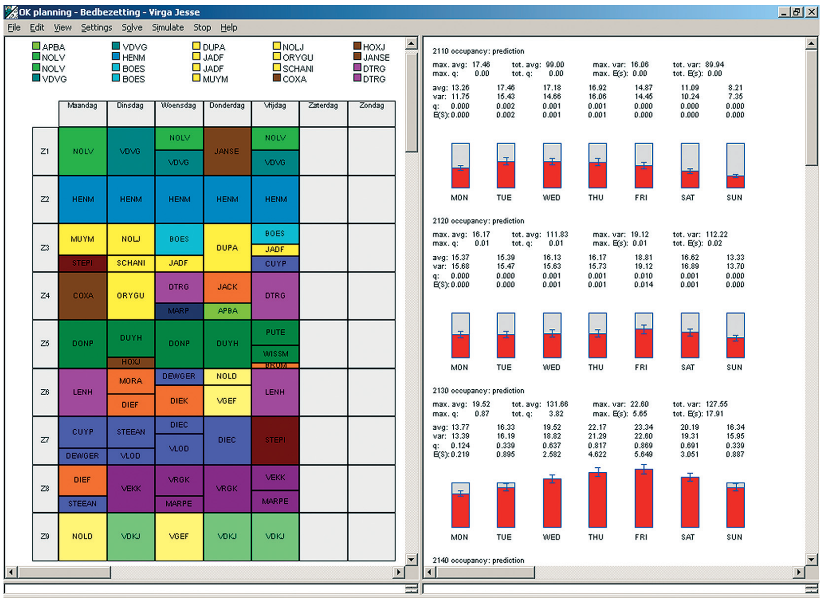
In the model that supports the visualization tool described in Section III, all resources are assumed to have a deterministic utilization, that is, the load can be predicted accurately. In reality, however, the utilization of certain resources is subject to high uncertainty. The use of equipment is typically deterministic, whereas the bed occupancy is in many cases difficult to predict, due to the uncertainty in the patient's length of stay. Moreover, the model neglects no-shows and uncertainty in the duration of the surgery. In other words, all resource consumption patterns are assumed to be deterministic. Therefore, Beliën and Demeulemeester (2006) propose an enhanced model that can be seen as a generalization, as well as a particularization, of the first model. It can be seen as a generalization, because it also takes uncertainty into account. The model is, however, also more specific, as beds are the only resource taken into consideration. The model starts from stochastic distributions for patient arrivals and a stochastic length of stay associated with each type of surgery. The objective is to obtain a leveled bed occupancy distribution and the master surgery schedule is again the main instrument to achieve this objective.

This new model has been tested using a case study in the Virga Jesse Hospital situated in Hasselt, Belgium (Beliën et al. (2007)). Virga Jesse's central operating room complex consists of 9 rooms in which a total of 46 surgeons have been assigned operating room time. Each operating room is open from Monday to Friday for 8.5 hours. The models applied in this study involve the development of a (cyclic) master surgery schedule with leveled bed occupancy in ten major wards.

Figure 3 shows a print screen of the GUI of the scheduling tool. Although the GUI exhibits many similarities, there are three important

FIGURE 3

GUI of the software tool for building master surgery schedules with leveled resulting bed occupancy taking into account uncertainty in the arrival and LOS of patients



differences with the previous system. First, the new model only focuses on the bed occupancy. The three rows that are shown at the right of Figure 3 each represent the weekly bed occupancy of a ward for which the bed occupancy on each day is predicted as a function of the master surgery schedule (shown left). Second, in contrast to the model of Section III, the new model explicitly takes uncertainty in the arrival and LOS of patients into account. This uncertainty is translated into bed occupancy distributions characterized by a mean (reflected by the height of the color of the bars) and a standard deviation (reflected by the small T-ending bars at the top of each colored part). Third, the new system not only allows for the visualization of resource conflicts, but also incorporates an optimization component that can be used to automatically generate a surgery schedule for which the resulting bed occupancy at the wards is leveled as much as possible. In this way, the bed occupancy at the wards can be maximally protected against unexpected peaks caused by a sudden increase of urgency cases on a particular day.

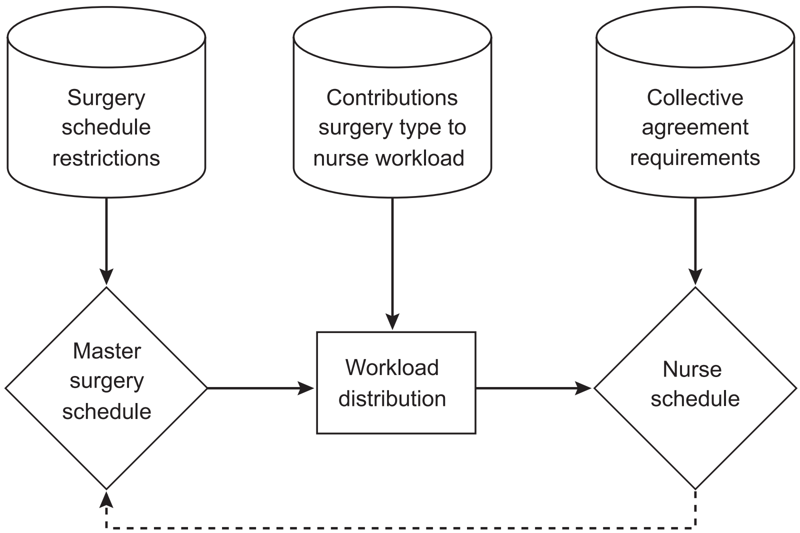
2. Integrating operating room and nurse scheduling

As nursing services account for an important part of a hospital's annual operating budget, concentrating on this resource can lead to substantial savings. The situation is exacerbated by an acute shortage of nurses in all Western countries, said to be 120,000 today and expected to grow to 808,000 by 2020 in the United States only (USDHHS (2002)). Hence, it is of vital importance that nurses are used as much as possible at the right time and at the right place.

The second, third and fourth resource in Figure 1 are groups of nurses, each having different skills. Observe that the need for nurses significantly varies over time. When the surgery schedule gives rise to peaks in the demand for nurses, it may be more difficult to schedule the nurses accordingly. Nurses have to be shifted from low demand shifts to peak shifts. Unfortunately, the nurse scheduling process is already constrained by itself. Indeed, when building the nurse schedule, different constraints have to be taken into account. These form an important hindrance for the flexibility with which nurses are scheduled. For instance, a nurse cannot be scheduled to work a morning shift when this same nurse is already scheduled to work an evening or night shift the preceding day. Another example includes the total number of shifts worked during weekends, which often must be equally divided among the different nurses. Taking into account these types of constraints that apply on the individual nurse schedules, a complete schedule (roster) including all nurses must be built that ensures the presence at the right time of the right number of nurses with the right skills. The timing of the requirement of nurses is determined by the number and type of patients present in the system which on its turn is determined by the master surgery schedule (see Section III). Hence, to obtain an efficient system, it is very important to have a good integration between the nurse scheduling process and the master surgery scheduling process.

A specific model and algorithmic solution procedure to realize this integration is proposed by Beliën and Demeulemeester (2007). Figure 4 contains a schematic overview of the model developed in this work. The input for the nurse scheduling process (at the right) consists of the restrictions implied on the individual nurse roster lines (which are called collective agreement requirements) on the one hand and the workload distribution over time on the other hand. The workload distribution itself depends on the master surgery schedule, since the timing of surgery determines which type of patients will be in the

FIGURE 4
Integrating nurse and surgery scheduling



system at what time. In order to be able to deduce the workload from the surgery schedule, one also has to know the workload contributions of each specific type of surgery. The dotted arrow at the bottom indicates the feedback that could be given from the nurse scheduling process to the surgery scheduling process in order to produce more favorable surgery schedules with respect to the resulting workloads and, as a consequence, more favorable nurse schedules. However, the freedom in modifying the surgery schedule is limited, since the master surgery schedule itself is restricted by a set of specific surgery constraints (e.g. capacity and demand constraints). The computational results presented indicate that considerable savings could be achieved by integrating the nurse and surgery scheduling process.

B. *Operational level*

With respect to the operational level, we already mentioned in Section III.B that a sequence of individual surgeries has to be determined within each operating room (i.e. the population of patients is known). In particular, we developed operational scheduling algorithms in cooperation with the surgical day-care center at the university hospital Gasthuisberg in Leuven (Belgium), which is the same medical facility that has been introduced in Section III. The quality of the surgery schedule is evaluated with respect to multiple objectives. This means that we want to start the surgeries of children and prioritized patients as early as possible. The priority given to children could, for instance, be explained by the difficulty for them to stay sober for an entire day. Furthermore, we want to incorporate the travel distance of patients to the day-care center. Scheduling patients with a large travel distance early on the surgery day would increase the risk for delays and would decrease the patient satisfaction. Next, we also want to avoid that patients need care when the day-care center closes. This would result in unexpected hospitalizations and would represent a major cost for the hospital. Finally, we want to level the bed occupancy in the two recovery rooms that are present in the hospital setting. We already mentioned that a leveled bed occupancy leads to a leveled workload for the nursing personnel and consequently reduces working pressure. Unfortunately, when a sequence performs well with respect to one criterion, the contrary might hold for the other criteria. Therefore, we need optimization algorithms that incorporate implicit trade-offs between the different objectives. Furthermore, we also have to take the limited availability of the resources into account. These resources vary from recovery beds to surgical instrument sets and their corresponding sterilization time. Note that the framework, determined by the master surgery schedule, cannot be violated and introduces additional constraints.

Multiple solution approaches are developed in order to optimize this difficult scheduling problem. These algorithms differ according to the optimization methodology (pure integer programming, branch-and-bound, column generation or branch-and-price) and their application with respect to, for instance, the allowed solution time and solution space (exact or heuristic). Since we are working on the operational level, qualitative solutions have to be generated quickly, i.e. less than 5 minutes. A detailed description of the surgical case scheduling problem described in this section and some corresponding solution approaches can be found in Cardoen et al. (2006).

VI. CONCLUSIONS AND FUTURE RESEARCH

In this paper, multiple algorithms and software tools were presented in order to generate qualitative surgery schedules on the tactical and operational level. We indicated that the efficient use of the operating theater improves the organizational efficacy of a hospital as a whole, since this facility is interrelated to many other departments or organizational problems (e.g. personnel scheduling, bed leveling or instrument sterilization). We indicated that the advantages of an adequate surgery scheduling process do not only apply to the hospital, but also to the patients. In fact, the surgery schedule can contribute to the patient satisfaction by, for instance, equilibrating the patient flow or incorporating patient specific information (e.g. age or travel distance). This quality of care could further be improved by integrating all processes described in the clinical pathways since this concept focuses on both the medical and organizational issues. Such intensive integration, however, is complex for today's algorithms and constitutes an area for future research.

Embedding the algorithmic approaches in a flexible GUI augments the applicability of the solution approaches. On the one hand, visualization can provide additional insights to the health managers and guide them through a process of trial and error for hypothesis testing or for triggering organizational discussions. On the other hand, they can present schedule outcomes that would surpass the experience of the health manager due to the inherent complexity of the surgery scheduling process, specifically when it is related to other facilities. Only on the tactical level of the surgery scheduling process, our research group could provide a software application for visualization and optimization. On the operational level, however, we still lack a visualization tool although we already possess knowledge for optimizing a multiple objective surgery schedule. The development of a software tool for scheduling surgeries on the operational level is a subject for future research.

Finally, intensive research should be performed on the strategic level of the surgery scheduling process, since these decisions mainly determine the financial revenues of many stakeholders, the positioning of the hospital with respect to innovation and the general setting in which qualitative tactical and operational surgery schedules have to be developed.

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